

Geophysical and Hydrochemical Evaluation of Springwater Potential and Quality within the Basement Complex Of Southwestern Nigeria

¹Ogundana, A.K., ²Aladejana, J.A.,

¹Department of Geology, Afe Babalola University, Ado-Ekiti.

²Department of Geology, University of Ibadan.

-----ABSTRACT-----

Groundwater in the basement complex terrain is known to be restricted to the weathered overburden and fractured rocks. Consequent upon this, groundwater availability becomes a challenge in any geological environment with low rock fracture and shallow overburden thickness. High history of borehole failure in this area necessitates search for alternative sources of water to complement the water demand. Geophysical and hydrochemical evaluation of spring water located on a basement complex was conducted to investigate its potential and quality for possible development. Combination of vertical electrical sounding and profiling methods were employed using Schlumberger and dipole dipole configurations respectively. Seven points were sounded along two traverses and two profiles were occupied around the main spring. Four (4) water samples were collected and analysed for physicochemical parameters. Flow rate was measured using flow-meter at six (6) different times from which the average was determined. Four different subsurface lithologic units were established namely; lateritic clay topsoil, clayey-sand, weathered basement and, fresh basement. The curve types range between simple H and HA. The topsoil thickness is relatively thin along these traverses. The average resistivity and thickness values for the topsoil are $181\Omega m$ and 2.0m respectively, which is predominantly lateritic clay. Clayey-sand was encountered at shallow depths of 2.0meters on the average in all locations and the average resistivity and thickness values for the Clayey-sand are, $24\Omega m$ and 9.0m respectively. The overburden is assumed to include all materials above the presumably fresh basement. The depth to the bedrock varies from 7.0 to 19.0m and the average depth to the bedrock is 13.0m. The Clayey-sand with an average thickness of 9.0m is the aquifer which responsible for the accumulation of the water with the lateritic clay top soil of 2.0m on an average acts as a protective layer. Shallow overburden thickness (1.0m) which intercept with the surface is responsible for the spring water at this spot. The impermeable crystalline basement rock underline the area prevents further percolation of the water. Hence, the accumulation and flow as spring becomes necessary. Hydrochemical analysis of water samples from the spring and other points at the downstream revealed that the spring water fall well within the acceptable limit of both World Health Organisation (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). This result also revealed higher value of Mn and Fe as the water flows away from the spring spot indication an anthropogenic influence. The flow rate estimated at 0.16L/Sec which is equivalent to 14,400L/day is significant if sustained throughout the year. So far, hydrochemical results suggest the fresh spring water is of good quality; however, there is need for the bacteriological analysis to be carried out to eliminate any doubt of probable bacteriological contamination.

KEY WORDS: Spring Water, Evaluation, Quality, Potential and Development.

Date of Submission: 20 March 2014



Date of Publication: 25 May 2014

I. INTRODUCTION

Access to clean water is a human right and a basic requirement for economic development. The safest kind of water supply is groundwater. Since groundwater normally has a natural protection against pollution by the covering layers, only minor water treatment is required (Reinhard 2006). The challenges of erratic groundwater resources are understood to be associated with any community underlying by basement complex around the world. This is due to the crystalline nature and mineralogical complexity in the rocks associated with this type of geological environment. Groundwater occurrence in this zone is found within the pore spaces of the

weathered overburden and also the fractures or other structural discontinuities such as joint or displacement related to intrusion or tectonic activities. These units serve as the aquifer for groundwater accumulation which largely depends on the nature/thickness of weathered overburden and structural spacing. This challenge becomes more complicated if the rocks underlying the zones are not fractured. Spring catchments are frequently dominated by hard rocks comprising intact rock bodies separated by discontinuities termed fractures. Depending on the type of rock, the porosity of intact rock bodies ranges from nearly zero to values much higher than the porosity created by fractures (Rehrl and Birk, 2010). The permeability of intact rock bodies is often relatively low though. Thus, discontinuities provide the major flow paths in fractured rocks. Groundwater exploration reports around Ado-Ekiti suggest low fracture in most part of this state capital. This results in low yield in most of the boreholes own by private individual and public. In the light of the above, it is not a gain saying to describe any area with spring water as a blessed zone. It is therefore encouraged that this spring should be investigated and assessed for its sustainability in terms of yield, quality and possibility to enhance its recharge rate to complement the available erratic source of water supply to meet ever increasing water demand for various purposes.

Afe Babalola University located in Ado Ekiti is not exempted from the challenge of low groundwater availability resulting from complex geology of this area. Hence, the Management is faced with the need to source for alternative means to complement the existing water supply for the ever-increasing population of the University community. Thus, the need to investigate and evaluate the springwater potential and assess the quality of the existing spring within the campus for improved water supply. Several workers such as Dutcher and Garret (1965), Clerk (1985), Olorunfemi and Olorunniwo (1985), Olorunfemi (1990), Olayinka and Olorunfemi (1992) Olorunfemi and Olayinka (1992), Olorunfemi and Fasuyi (1993), Oladipo et al, (2005) Olayinka and Weller (1993), Rehil and Birk (2010), Ojo et al, (2011), Talabi (2013) have carried research in various aspect of groundwater exploration/investigation, evaluation and structural delineation using geophysical methods in several location within the basement complex terrain around the world.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

The study spring is located at the southwestern part of the University campus just at the back of the power house and adjacent of the University guest house under construction. It lies at longitudes $5^{\circ}18'05.78''\text{E}$ and latitudes $7^{\circ}36'09.59''\text{N}$ (Figure 1). The terrain in the study area is gently undulating, with topographic elevation ranging from 345m to 370m above sea level. Ado Ekiti is underlain by crystalline rocks made of Older granite, Migmatite and Charnockites which are of little or no fracture in most location with accompanied shallow overburden.



Figure.1: Aerial Photo of the Study Location

Climate, Geology and Hydrogeology of The Area

The area is situated within the tropical rain forest region, with a climate characterized by dry and wet seasons. Average annual rainfall in this area is 1300 mm, with average wet days of about 100. The annual temperature varies between 18°C to 34°C . The study area lies within the basement complex of south-western Nigeria and is older granite, Migmatite and Charnockites which are of little or no fracture in most location with accompanied shallow overburden. The overburden is relatively shallow within the study area with average of 13m. The groundwater is found within the overburden and fractured basement while the area is drained by the river Ogbese which flow SW-NE direction.

III. METHODOLOGY, DATA ACQUISITION AND INTERPRETATION

A reconnaissance survey of study spring was carried out for site familiarization and planning. This was followed with geophysical investigation of the spring site and environs. Geophysical methods are indirect site investigation techniques and predominantly non-intrusive. Two methods namely; Resistivity Sounding and Resistivity Profiling were adopted. Soil resistivity meter (PASI) was used for the geophysical tests. It is highly reliable and reproducible. Resistivity sounding was adopted in resolving resistivity variation with depth, thus sounding helped in delineating the various subsurface lithological units, hydrogeological significance and the protective capacity or vulnerability of the subsurface layers to possible pollution. Resistivity profiling was adopted in resolving horizontal resistivity variation in this study, hence profiling helped in establishing the lateral continuity of the various subsurface lithological units. The local geology of the area was studied and the existing hydrogeology pattern was observed. Other existing water bodies around the spring were also monitored. Physico-chemical parameters such as pH, temperature, electrical conductivity (EC), total dissolved (TDS) solids were determined on the field using portable multistest meter. Water samples were taken for physiochemical analysis. Hydrochemical studies was conducted on the water sampled from the spring and three other points from within 200meters downstream at an average of 50m intervals were collected for both major ions and heavy/trace metals analysis. Major cations and heavy/trace metals were analysed using Atomic Absorption Spectrophotometer while Major anions were analysed using spectrophotometer and ion chromatography. Hydrological approach was adopted to determine the flow rate of the spring. This was carried-out using flow meter.

IV. RESULTS AND DISCUSSIONS

Vertical Electrical Sounding

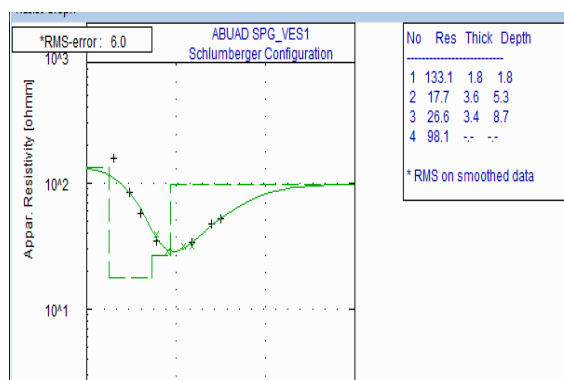
A total of 7 VES locations across 2 traverses were spread over the study area (Figure 1). The processed data were interpreted, resulting curve types were assessed, existing subsurface lithologic units were established, and the geoelectric properties of the various subsurface layers were used in delineating the aquiferous units responsible for the spring in the study area. The results are presented in the form of table (Table 1), geoelectric curves (Figure3) and sections (Figure 4a & b).



Figure.2a and b: Picture showing Geophysical field data acquisition and Physico-chemical measurements

Four different subsurface lithologic sequences were established namely; lateritic topsoil, clayey-sand, weathered basement and, basement. The curve types range between simple H and HA. The topsoil, clayey-sand and weathered basement materials are characterised with relatively low resistivity values while the basement materials are typified with high resistivity values.

A summary of the results of interpretation, on which the following findings were hinged, is shown in Table 1.



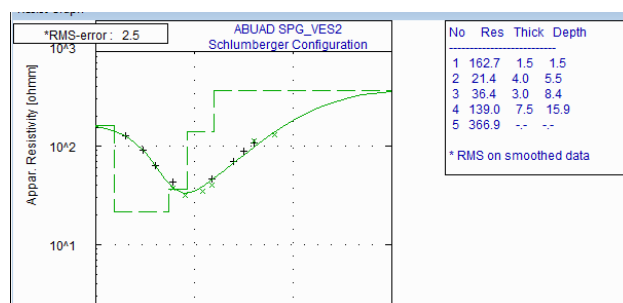


Figure.3: Typical Geoelectric curves from data interpretations

Table 1: Correlation Table

VES POINT		1	2	3	4	5	6	7
CURVE TYPE		H	HA	HA	HA	H	HA	H
LITHOLOGY								
TOP SOIL	TOP	0	0	0	0	0	0	0
	BASE	2	1	3	1	2	4	1
	THICKNESS	2	1	3	1	2	4	1
	Ωm	133	163	103	207	249	272	139
CLAYEYSAND	TOP	2	1	3	1	2	4	1
	BASE	9	8	8	7	19	11	15
	THICKNESS	7	7	5	6	17	7	14
	Ωm	27	36	16	23	29	10	29
WEATHERED BASEMENT	TOP	9	8	8	-	-		15
	BASE	-	16	-	-	-		-
	THICKNESS	-	6	-	-	-		-
	Ωm	98	139	126	-	-		156
BASEMENT	TOP	-	16	-	7	19	11	-
	Ωm	-	367	-	279	249	277	-

Geoelectric Units

The geoelectric sections (Figures 4) show the variations of resistivity and thickness values of layers within the depth penetrated in the study area at the indicated VES stations. The two traverses were taken along the N-S directions. Generally, the traverses revealed four subsurface layers: Lateritic Top-soil, Clayey- sand, Weathered basement and the presumed Fresh basement.

Topsoil

The topsoil thickness is relatively thin along these traverses. The average resistivity and thickness values for the topsoil are $181\Omega m$ and 2m respectively, which indicated that the predominant composition of the topsoil is lateritic clay.

Clayey-sand

Clayey-sand was encountered at shallow depths of 2meters on the average in all locations and the average resistivity and thickness values for the Clayey-sand are, $24\Omega m$ and 9m respectively.

Weathered-basement

Weathered-basement was encountered in four locations and the average resistivity value and depth to the top of the weathered-basement are, $130\Omega m$ and 10m respectively thus indicating that the material composition is largely clay, sandy-clay and clayey-sand or high degree of water saturation. The thickness values were not established in some of the locations.

Basement

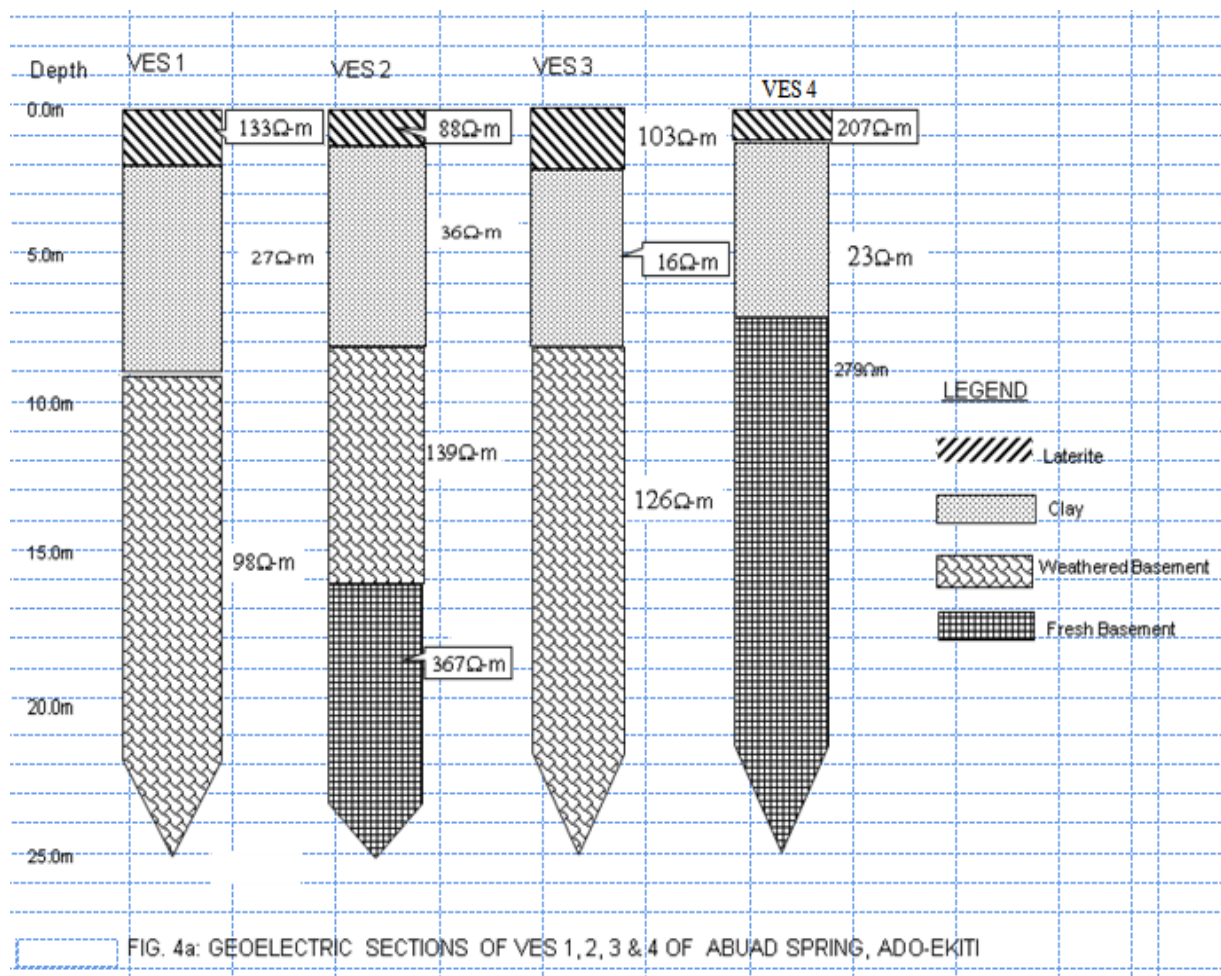
The basement is the fresh bedrock and is the last layer. It is relatively shallow in the study area, it was encountered in four locations and the average resistivity and depth values to the top of basement are, 293 Ω m, and 13m respectively. The resistivity values are high because of its crystalline nature.

Overburden

The overburden is assumed to include all materials above the presumably fresh basement. The depth to the bedrock varies from 7.0 to 19.0m and the average depth to the bedrock is 13.0m (Table 1 and Figure 4). Overburden thickness was established in four locations and the average thickness value is 13.0m. The relatively moderate overburden thickness has potentials for groundwater saturation, however, the clayey nature and poor permeability of the materials will pose a challenge for water abstraction.

Horizontal Profiling

Result of the profiling carried out across two traverse sections in E-W direction is presented in the following section. The first traverse is 55meters long and is located 50meters before the spring while the second traverse is 60meters long and is located right on the spring. Four continuous subsurface lithologic units namely; Lateritic topsoil (blue), clayey-sand (green), weathered basement (yellowish-brown) and fresh basement (reddish purple) were established by the two profile sections. The results are presented in form of field data pseudosections and 2-D resistivity structures (Figure 5 & 6). The pseudosection and 2-D resistivity plot revealed a relatively thin overburden and shallow basement at the spring spot (Station 4 on figure 5 & 6) which invariably responsible for the discharge at that point.



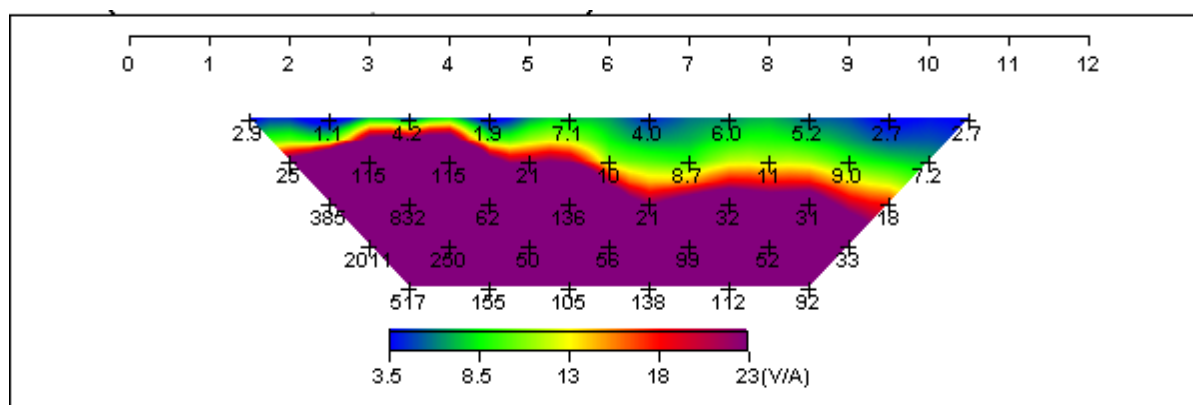
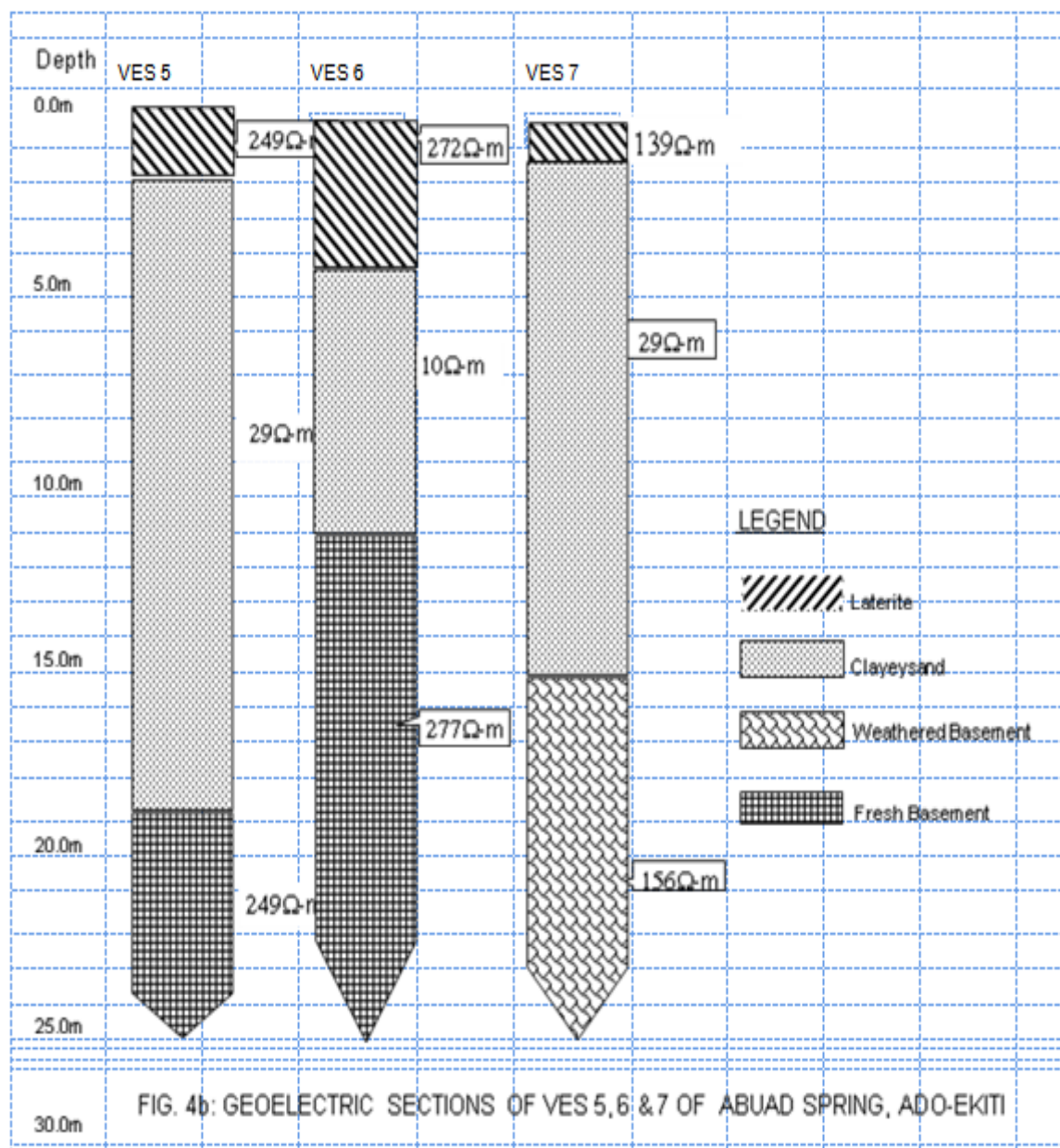


Figure. 5a Field Data Pseudosection of Profile 1

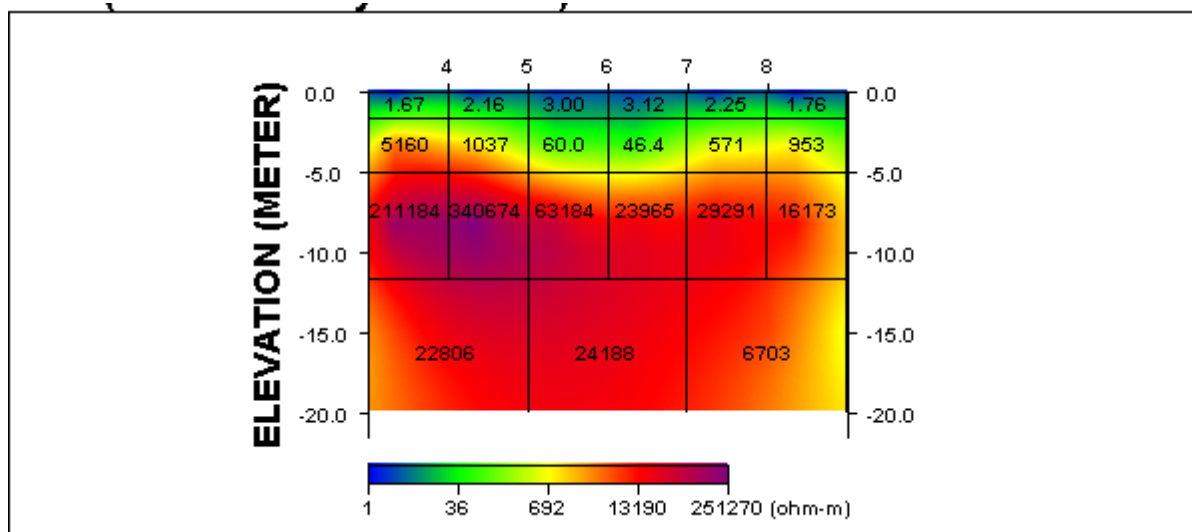


Figure. 5b 2-D resistivity structures of Profile 1

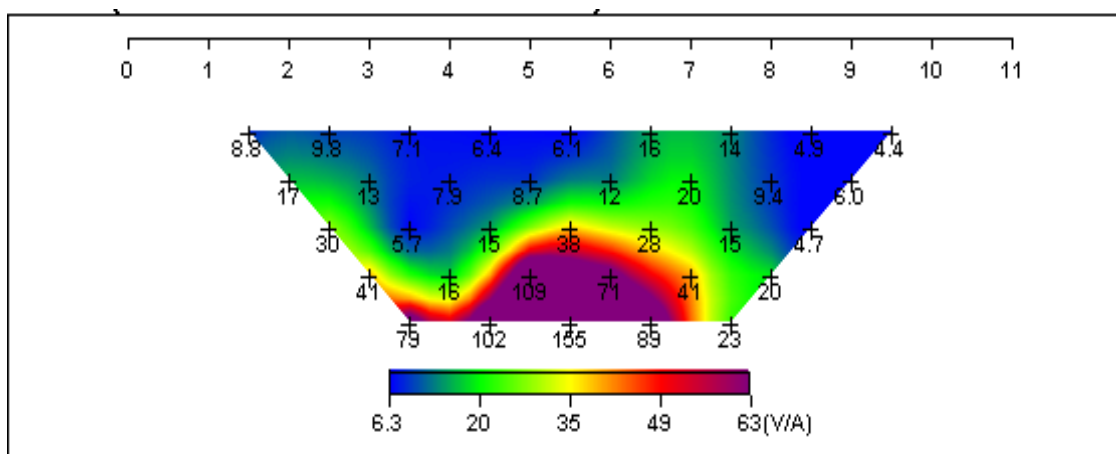


Figure. 6a Field Data Pseudosection of Profile 2

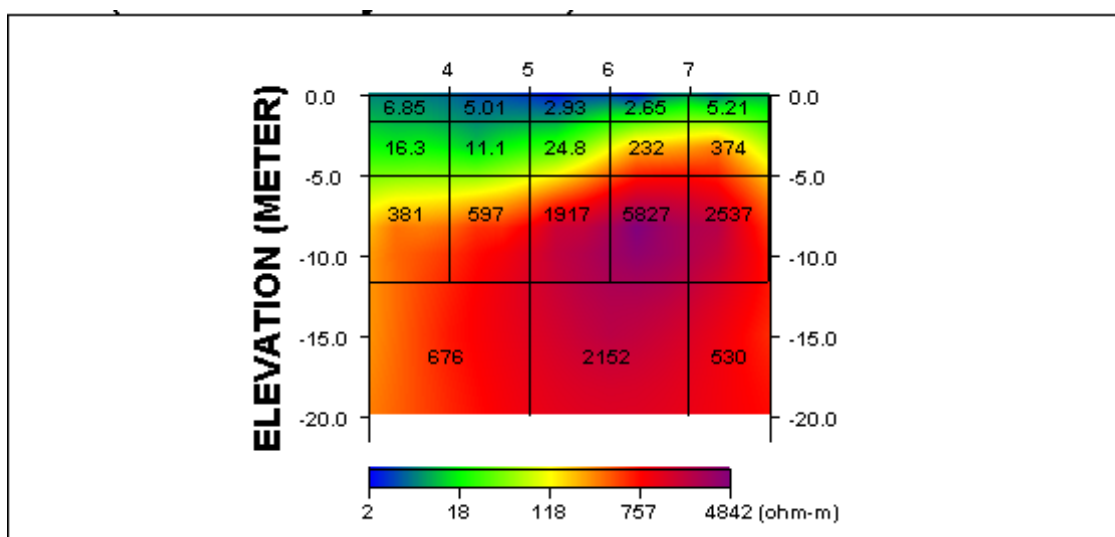


Figure. 6b 2-D resistivity structures of Profile 2

V. RESULTS OF HYDROCHEMICAL ANALYSIS

Results of the hydrochemical analysis of the water samples are as presented in the Table 2 above. Results of physico-chemical parameter revealed temperature ranges from 23.6 to 26.8 with average value of 25.35°C while pH, TDS and EC revealed range of 6.0-7.2, 52.5-301mg/l, and 74.5-426µS/cm with their respective average values of 6.75, 126.05mg/l and 178.375µS/cm. Major cations Ca^{2+} , Mg^{2+} , K^{+} , and Na^{+} revealed ranges of (2.43-20.24), (2.56-13.36), (0.51-1.34) and (3.02-21.35mg/l), with respective average of 7.52, 5.72, 0.97 and 8.14mg/l. Anions HCO_3^- , Cl^- , SO_4^{2-} and NO_3^- ranges from 57.6-108, 172-61, 0.79-2.52 and 25.64-28.93mg/l with respective average of 82.8, 31.75, 1.3 and 17.14mg/l respectively Table 3. Fe and Mn range from 0-6.15 and 0.32-16.23mg/l with their respective average values of 1.62 and 4.4mg/l. Metals such as Cu, Zn, Co, Cr, Cd, Pb and Ni all showed concentrations below the detectable limit of the analytical instrument used. The hydrochemical results were compared with both WHO and NSDWQ standards to further establish its quality. All the ions and metals in the fresh spring water sample fell well within the permissible limit of both standards. Increase in groundwater composition was observed as the water flow away from the spring spot, this could be attributed to anthropogenic influence from the surrounding.

Hydrochemical Characterisation

In a bit to further understand the hydrochemical characteristics of the study spring water Schoeller semi-logarithmic diagram (Schoeller, 1967) was employed. This allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be easily discriminated. The Schoeller diagram shows the total concentration of major ions in log-scale. Results of the Schoeller plots (Figure 7) revealed Ca^{2+} as dominant cation and HCO_3^- , Cl^- as dominant anions with fingerprint of $\text{Ca}^{2+} > \text{Na}^{+} > \text{Mg}^{2+} > \text{K}^{+}$ and $\text{HCO}_3^- > \text{Cl}^- > \text{NO}_3^- > \text{SO}_4^{2-}$ for both anions and cations. The relative ionic composition of the studied spring waters were plotted on a Piper Trilinear diagram as presented in Figure 6 (Piper, 1944). This diagram provides a convenient method to classify and compare water types based on the ionic composition of different water samples (Hem, 1985). Cation and anion concentrations for the spring waters were converted to meq/l and plotted as percentages of their respective totals in two triangles (Figure 8). Subsequently, the cation and anion relative percentages in each triangle were then projected into a quadrilateral polygon that describes the water type or hydrochemical facies. The values obtained from the analyzed spring waters samples and their plot on the Piper's diagram (Piper, 1944), revealed Ca^{2+} as the dominant cation while HCO_3^- is the dominant anion. In the study area, the major spring water type is Ca- HCO_3 with Ca-(Cl)- HCO_3 characterised (Figure 8) based on (Back and Hanshaw, 1965). The plausible explanation as to the evolved water type was from weathering induced through high precipitation that characterized the study area. However, anthropogenic contributions cannot be ruled out in view of increase in the number of tourists visiting the spring site.

Hydrological/Flow Characteristics of the Study Spring

The present flow rate was estimated at 0.16L/Sec from which the relevant calculation was done to generate its equivalence as 14,400L/day. The average daily water requirement per person in Nigeria is 30L/Day (UNDP 2008), hence, the spring in its present state has the capacity to meet the average daily water requirement of about 480 people.

Table. 2: Results of the Hydrochemical Analysis

PARAMETER	ABSP-1	ABSP-2	ABSP-3	ABSP-4	MIN	MAX	AVER	STDEV	WHO[2004]	NSDWQ[2007]
Temp(C)	26.8	25.8	25.2	23.6	23.6	26.8	25.35	1.34	27	27
pH	6.0	6.7	7.1	7.2	6	7.2	6.75	0.54	6.5-8.5	6.5-8.5
TDS (Mg/l)	52.5	67.7	83.0	301.0	52.5	301	126.05	117.296	500	500
EC (µS/cm)	74.5	95.0	118.0	426.0	74.5	426	178.375	166.037	900-1200	1000
Mn (Mg/l)	0	0.1	0.22	6.15	0	6.15	1.6175	3.023	0.3	0.2
Fe (Mg/l)	0.32	0.81	0.53	16.23	0.32	16.23	4.4725	7.8409	0.3	0.3
Cu (Mg/l)	0	0	0	0	0	0	0	0	1	1
Zn (Mg/l)	0	0	0	0	0	0	0	0	3	3
Co (Mg/l)	0	0	0	0	0	0	0	0	0.01	0.01
Cr (Mg/l)	0	0	0	0	0	0	0	0	0.01	0.05
Cd (Mg/l)	0	0	0	0	0	0	0	0	0.01	0.03
Pb (Mg/l)	0	0	0	0	0	0	0	0	0.3	0.01
Ni (Mg/l)	0	0	0	0	0	0	0	0	0.02	0.02

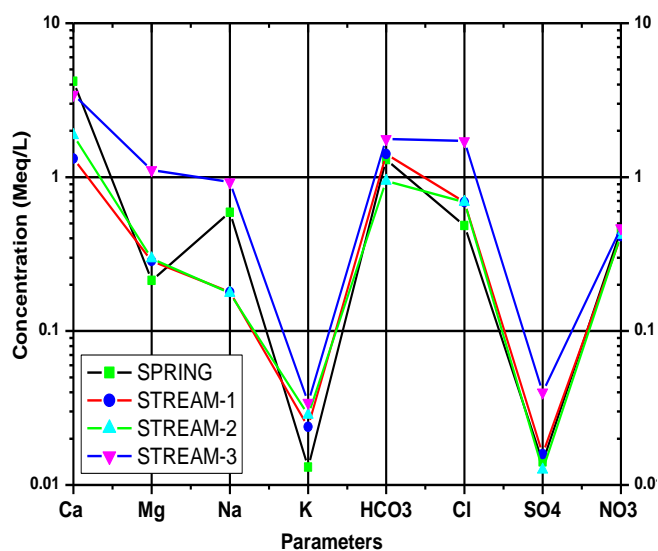


Figure 7. Schoeller diagram of the Major oxides in the spring water.

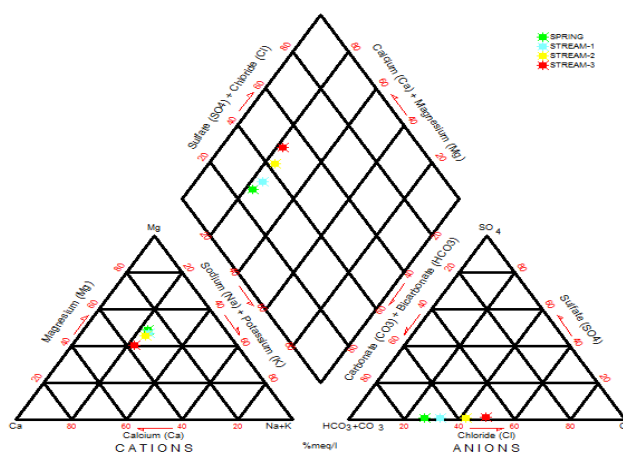


Figure 8. Piper Trilinear diagram of the spring water.

Table 3. Results and Statistical Summary of Major Oxides of the Water Samples

Parameters	Ca	Mg	K	Na	HCO3	CL	SO4	NO3
Sample ID	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l
ABSP-1	2.43	2.56	0.51	3.02	79.2	17.2	0.89	27.88
ABSP-2	3.44	3.42	0.93	4.13	86.4	24.4	1	25.64
ABSP-3	3.95	3.55	1.11	4.06	57.6	24.4	0.79	26.11
ABSP-4	20.24	13.36	1.34	21.35	108	61	2.52	28.93
MIN	2.43	2.56	0.51	3.02	57.6	17.2	0.79	25.64
MAX	20.24	13.36	1.34	21.35	108	61	2.52	28.93
AVER	7.515	5.7225	0.9725	8.14	82.8	31.75	1.3	27.14
STDEV	8.50681	5.11058	0.35103	8.82128	20.7846	19.7932	0.81784	1.53434
WHO[2004]	75	50	10	50	100	250	250	50
NS[2007]	75	50	10	50	100	250	100	50

This figure can be improved with further enhancement of the discharge of the spring. This is contrary to an earlier estimate quoted at 2.0L/Sec which is equivalent to 172,800L/day in the previous investigation. However, the current estimated flow rate is significant if sustained throughout the year.

VI. CONCLUSION AND RECOMMENDATIONS

Geophysical and hydrochemical evaluation of the spring water located within the campus of Afe Babalola University, Ado-Ekiti has been undertaken. Four subsurface layers namely; Lateritic Top-soil, Clayey-sand, Weathered basement and the presumed Fresh basement were delineated and the aquiferous layer responsible for the accumulation of the spring water was identified to be the Clayey-sand unit. The thin (1.0m) lateritic overburden thickness and the shallow basement depth at the spring spot is responsible for the discharge at this point. The lateritic clay topsoil serves as the protective unit for the aquifer against possible surface contaminant infiltration. Hydrochemical analysis of water samples from the spring and other points at the downstream revealed that the spring water fall well within the acceptable limit of both World Health Organisation (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). Hydrochemical characterization of the water using Piper trilinear diagram suggested Ca-HCO₃ water type which indicates a product of rock-water interaction. The present flow rate was estimated at 14,400L/day and average daily water requirement per person in Nigeria is 30L/Day (UNDP 2008), hence, the spring in its present state has the capacity to meet the average daily water requirement of about 480 people. This figure can be improved with further enhancement of the discharge of the spring. However, the current estimated flow rate is significant if sustained throughout the year.

Finally, the following recommendations are made;

- [1] The flow rate of the spring should be monitored during dry season.
- [2] Bacteriological analysis should be carried out to eliminate any doubt of probable bacteriological contamination.
- [3] Geotechnical reinforcement of the spring discharge area should be undertaken to enhance and optimise the discharge from the spring.
- [4] Channels and Subsurface storage facility should be constructed after detail geotechnical and geophysical investigation to evaluate the embankment requirement of the study area.

REFERENCE

- [1] Pearce, A. J., Stewart M. K. and Sklash, M. D. 1998, Storm runoff generation. *Water resources research*. Vol. 22. No 8. P1263-1272.
- [2] Back, W. and Hanshaw, B (eds), *Chemical geohydrology advances in hydrosience*; (Academic Press), 1965, pp. 49-109.
- [3] Birk S, Liedl R, Sauter M (2004) Identification of localized recharge and conduit flow by combined analysis of hydraulic and physiochemical spring responses(Urenbrunne, SW-Germany). *J Hydrology* 286: 179-193
- [4] Rehl, C. and Birk, S. 2010, Hydrogeological Characterisation and Modelling of Spring Catchments in a Changing Environment. *Austrian Journal of Earth Sciences* Volume 103 Issue 2, p106-117 Vienna.
- [5] Clerk L (1985). Groundwater Abstraction from Basement Complex Areas of Africa. *J. Eng. Geol.*, London 18: 25-34.
- [6] Dutcher, L.C. and Garrett. A.A., 1963, *Geologic and hydrologic features of the San Bernardino area* , California: U.S.Geological survey Water-Supply Paper 1419, 114p.
- [7] Grant, F. S., West, G. F, (1965). *Interpretation theory in Applied Geophysics*. New York, McGraw-Hill
- [8] Hem, J. D, *Study and interpretation of the chemical characteristics of natural water*. US Geological Survey Water-supply Paper, 1985, 2254, 3rd ed., p263.
- [9] Nigerian Standard for Drinking Water Quality, NSDWQ. Published by Nigerian Industrial Standard 2007, 554, 1-14.
- [10] Ojo, J.S., Olorunfemi, M.O. and Falebita, D.E, An Appraisal of the Geologic Structure beneath the Ikogosi Warm Spring in South-Western Nigeria Using Integrated Surface Geophysical Methods. *Earth Sciences Research Journal*. 2011, 15(1):27-34.
- [11] Oladipo, A. A., Oluyemi, E. A., Tubosun, I. A., Fasisi, M. K. and Ibitoye, F. I, Chemical Examination of Ikogosi Warm Spring in South Western Nigeria. *Journal of Applied Sciences*, 2005, 5 (1): 75-79
- [12] Olayinka A. I. and Weller A. 1997. The inversion of geoelectrical data for hydrogeological applications in crystalline basement areas of Nigeria. *Journ. of Applied Geosciences*, Vol. 37, Issue 2, June 1997, pp 103 – 105.
- [13] Olayinka A. I, and Olorunfemi M. O. (1992). Determination of geoelectrical Characteristic in Okene Area and implication for boreholes setting. *J. Min. Geol.*, 28: 403 - 412.
- [14] Olorunfemi M. O. & Olayinka A. I. (1992): Alteration of Geoelectric in Okene are and Implication for Borehole Sitting. *Journal of Mining and Geology*, pp. 403-411.
- [15] Olorunfemi M. O. & Oloruniwo M. A. (1985): Geoelectric Parameters and Aquifer Characteristics of Some Part of South Western Nigeria. *Journal of Mining and Geology*. Part 1, pp. 99-109.
- [16] Olorunfemi M. O. (1990): The Hydrogeological Implication of Topographic Variation with Overburden Thickness in Basement Complex. Area of South Western Nigeria. *Journal of Mining and Geology*. Vol 26, No. 1.
- [17] Olorunfemi M. O. and Fasuyi S. A. (1993). Aquifer types and geoelectric/hydrogeologic characteristics of part of central basement terrain of Nigeria (Niger State). *J. Africa Earth Sci.*, 16(3): 309-317.
- [18] Oyawoye, M. O, 1964. The Geology of the Nigerian Basement Complex. *Journ. Nigerian Min. Geol. and Metall. Soc.* Vol 1. pp 108 - 117
- [19] Piper, A. M, A graphic procedure in the geochemical interpretation of water analyses. *Trans. Am.Geophy. Union* 1944, 25: 914-928.

- [20] Rahaman MA (1989). Review of the basement geology of southwestern Nigeria: In Geology of Nigeria (Kogbe CA Ed.). Elizabeth Publishing Co. Nigeria. pp. 41-58.
- [21] Rahaman, M. A. 1988. Recent advances in the study of the basement complex of Nigeria, Precambrian Geology of Nigeria, Pub. of the Geol. Surv. Of Nigeria, Kaduna pp. 11 – 41
- [22] Rahaman, M. N. 1976. Review of the basement geology of southwestern Nigeria, in geology of Nigeria, edited by C. A. Kogbe, Elizabethan pub. Co. Lagos. pp. 41 - 58
- [23] Schoeller, H. Geochemistry of groundwater. An international guide for research and practice. UNESCO, 1967, chap 15, pp 1-18.
- [24] Talabi, A. O., 2013, Hydrogeochemistry and Stable Isotopes ($\delta^{18}\text{O}$ and $\delta^2\text{H}$) Assessment of Ikogosi Spring Waters. American Journal of Water Resources, 2013, Vol. 1, No. 3, 25-33.
- [25] Tunbosun, I. A., Lancelot, J. R., Rahaman, M. A., Ocan, O. (1984). U/Pb Pan-African ages of two charnockite-granite associations from Southwestern Nigeria. *Contr. Min. Petrol.* Pp 88, 188-195.
- [26] UN, 1988. Ground Water in North and West Africa. Natural Resources/Water Series No. 18, United Nations, New York
- [27] US EPA (2003) National primary drinking water regulations. US EPA, Washington. DC
- [28] World Health Organization (WHO), "Guidelines for Drinking Water Quality", 2004, Vol.1: Recommendations (3rd edn). WHO, Geneva.